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Simulation based Study of FPGA Controlled Single-Phase Matrix Converter with Different Types of Loads

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Abstract— **In present days of electrical industries, adjustable speed controlled induction motor drives are very common** due to its versatile features**. For the speed control of induction motor, variable frequency sources are the heart of such drives. To attain variable frequency** and variable voltage **supply a power electronics device; single phase matrix converter is proposed.**
In this paper, the single phase matrix converter is modeled in MATLAB Simulink environment; controlled with **sinusoidal pulse width modulation technique,** control scheme is **implemented in a Xilinx system generator environment and interfaced with power circuit in MATLAB Simulink. Analyses this SPMC with different type of loads in both frequency step up and step down modes. Based on simulation results, this converter is suitable for variable frequency power supplies, varying load conditions and variable speed electrical drives. FPGA control is best suitable for controlling a circuit like SPMC, consists of more controlled elements to attain fast operation.**

Index Terms— **Cycloconverter, Field Programmable Gate Array (FPGA), Matrix Converter (MC), MATLAB/SIMULINK, Pulse Width Modulation (PWM).**

I. Introduction

The Cycloconverter is a power conversion system which generates variable frequency AC output from constant frequency AC input without involving any DC link capacitor. It can be circulating current type or blocking mode type. Blocking mode type is highly used commercially. Its power rating ranges from a few megawatts to tens of megawatts. It has the potential for affording power electronic device, AC-AC conversion is a best solution for removing the bulk DC capacitor which is placed to use in conventional systems between converter and inverter set up as reactive energy storage components [1-6].
In this paper, proposing an SPMC which can operate both as a cycloconverter and cycloinverter. The AC input waveform is converted to the AC output waveform at a lower frequency by a cycloconverter. Force Commutation is required. And AC input waveform is converted to the AC output waveform at a higher frequency by a cycloinverter. Natural commutation is used.
Matrix Converter (MC) topology was first proposed by Gyugyi in 1976, it is proposed to fulfill the disadvantages of a cycloconverter such as high conduction losses, having more harmonics etc. In addition to this it also has the ability to feed back the energy to the utility and it almost eliminates the reactive energy storage devices. As this matrix converter has the greatest capability to use in AC- AC conversion system and the capability to meet the ideal frequency changer, it has attracted by the researchers especially in the field of military and aerospace applications.
The Matrix Converter (MC) offers many advantages such as regeneration of energy fed back to the utility.

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MC has the potential of conversion from AC-AC. Since there is no conversion from AC to DC it doesn't require energy storage components such as large DC capacitors (electrolytic capacitors) or inductors which are used in conventional rectifier-inverters. It provides less high order harmonics in both input and output sinusoidal waveforms. It has been popular due to the potential benefits, especially for applications where, weight, size, and long term reliability are the important factors.

It has several advantages over conventional rectifier-inverter type frequency converters. It generates sinusoidal output waveforms with minimum harmonics and no sub harmonics. Secondly, it has bidirectional power flow capability inherent in itself. This facilitates regeneration of energy back to supply or grid. Also, there is a minimum requirement of storing energy which makes a MC free of bulky capacitors and inductors. Thirdly power factor can be also adjusted as per our needs.

In [7], a generalized 1-Φ matrix converter is designed, this MC (Matrix Converter) can be functioned as DC-AC inverter, DC-DC chopper, AC-DC converter, AC-AC voltage controller and frequency controller. Matrix converter has investigated under different R-L conditions in [8], also maximum voltage transfer ratio is obtained by controlling the converter with third harmonic pulse width modulation technique. In [9]-[10], Z-Source buck boost converter topologies have been proposed to increase or decrease the both frequency and voltage. In [9], a 1-Φ z-source buck boost matrix converter is designed; offers buck and boost the input voltage to the required output voltage level and also can step up or step down the output frequency. In [10], a new type of 1-Φ Z-source buck-boost matrix converter is proposed, to vary both the frequency and the voltage in either side i.e., stepped up or stepped down. This designed converter offers self commutation strategy without using any snubber circuit. In this paper, the single phase matrix converter is modeled in MATLAB Simulink environment**;** controlled with sinusoidal pulse width modulation technique**,** control scheme is implemented in a Xilinx system generator environment and interface**d** with power circuit in MATLAB Simulink. Analyses this SPMC with different type of loads in both frequency step up and step down modes. Based on simulation results, this converter is suitable for variable frequency power supplies, varying load conditions and variable speed electrical drives. FPGA control is best suitable for controlling a circuit like SPMC, consists of more controlled elements to attain fast operation.

II. Principle Of Operation

The Matrix Converter is a forced commutated converter which has an array of m × n bidirectional power switches which will connect any m-phase voltage source to any n-phase load to create a variable output voltage with unrestricted frequency. In practical the matrix converter of 3 × 3 switches, has the maximum attention because it links a three-phase voltage source with a three-phase load, normally the load is a motor which is shown in Figure 1. Input terminals of MC should not be short circuited because the matrix converter is fed by a voltage source and on the other hand the output phase must never be opened because it has a load of inductive nature.

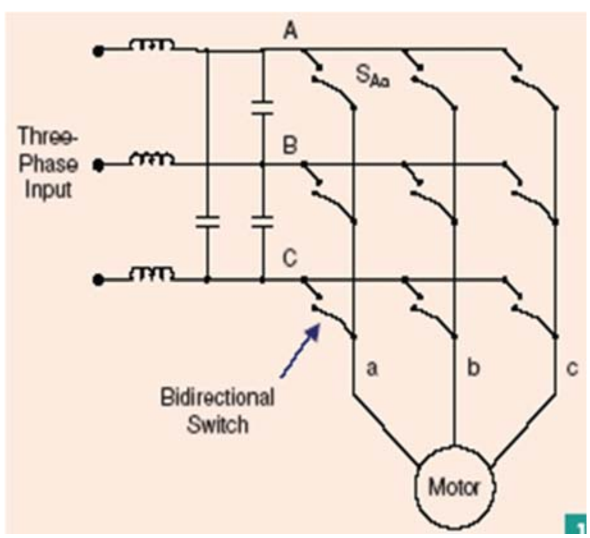

Figure 1: Basic circuit of 3-Φ matrix converter

A. Input Filter

Even though matrix converter does not consist of energy storage components, it requires a minimum of reactive components at the input side or source side represented by the input filter.
Usually the input filter is in between MC and AC mains shown in Figure. 2. The main function of this input filter is to avoid the significant changes in the input voltage of the converter at each PWM cycle, and it also prevents the input harmonic currents from AC mains.

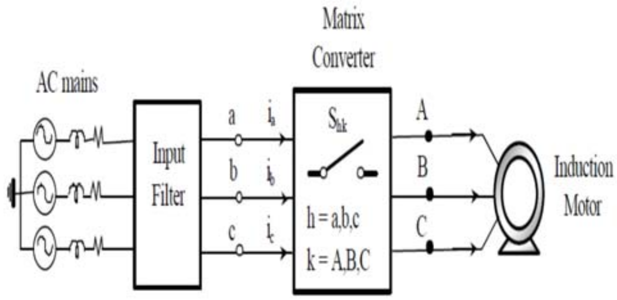

Figure.2: Schematic representation of a matrix converter with input filter

A SPMC requires 4 bi-directional switches as shown in Figure3. A bi-directional switch is realized by the combination of conventional unidirectional semiconductor devices like a diode bridge with single IGBT or two anti-parallel IGBT.

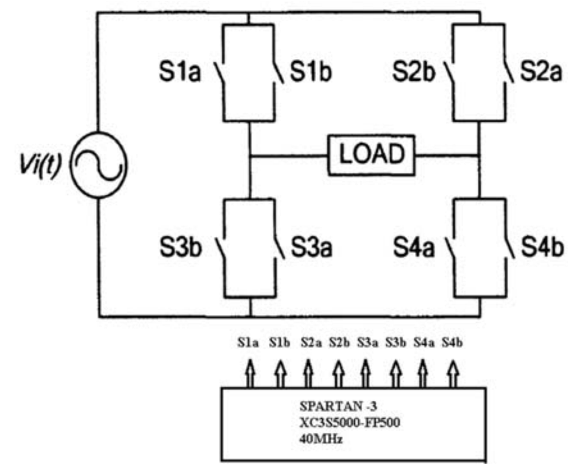

Figure3: Circuit diagram of SPMC

The frequency of the converter is changed by controlling the duration of operation of the switch. Switching sequences are given as below:

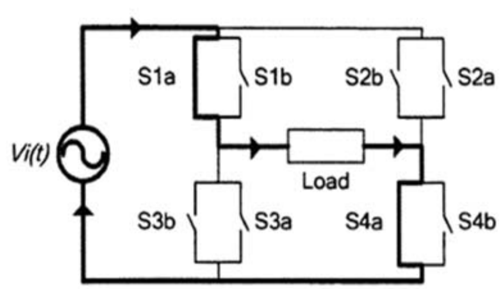

Figure3.1: State 1 (Positive Cycle)

Only two switches conduct at any time ‘t’ and state. In State 1, Switches 1 and 4 conduct during positive cycle of input source.

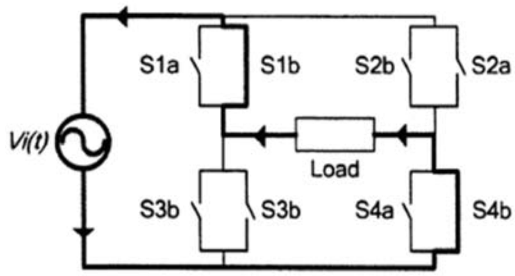

Figure3.2: State 2 (Negative Cycle)

In State 1, Switches 4 and 1 conduct during negative cycle of input source.

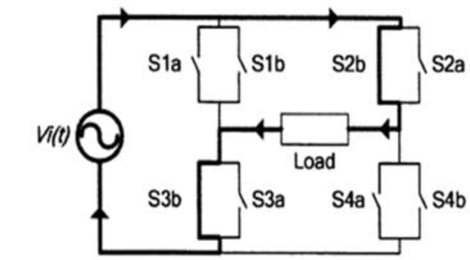

Figure3.3 State 3 (Positive Cycle)

In State 3, Switches 2 and 3 conduct during positive cycle of input source.

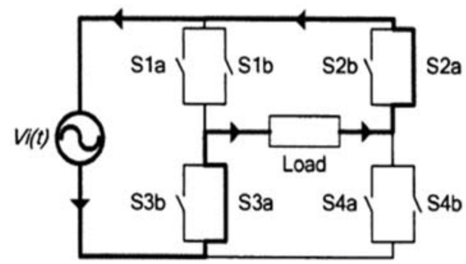

Figure3.4: State 4 (Negative Cycle)

In State 4, Switches 3 and 2 conduct during negative cycle of input source.

III. FPGA

The outputs of cycloconverter and cycloinverter contain a large number of harmonics. So to make them sinusoidal with high switching frequency, control scheme is implemented on FPGA platform. The field-programmable gate array is a new programmable logic device (PLD) developed by Xilinx, Inc. [2]. It consists of thousands of logic gates which are grouped together to simply the complex circuit.

It is advantageous over other traditional techniques. Firstly FPGA IO resource is abundant [3]. Secondly, the performance of FPGA to the design sequential logic circuits is good [4]. Thirdly, the difficulty and time cost for hardware design have been greatly reduced [5]. Also, the information is faster and the controller architecture can be optimized for space or speed [6].

IV. CONTROL TECHNIQUE

Simultaneous control of the both output voltage and current is possible with the help of matrix converter, but it is not easy to implement the simultaneous and independent control. The method for controlling the MC becomes complicated because turning ON one bidirectional switch causes the change in input current condition. The control method for a MC is the pulse pattern is calculated for each bi-directional switch is obtained directly from the condition input becomes a sinusoidal wave. However it is difficult to control the both input current and output voltage independently since the pulse pattern is calculated directly.

A new control method was developed based on virtual indirect control of a PWM rectifier and inverter. The pulse pattern is obtained in this technique by synthesizing the pulse pattern of both virtual PWM rectifier and inverter. With this control technique independent control action is possible on input current and output voltage. The principle of virtual indirect control method states, “in a three phase power converter, input and output waveforms will not depend on circuit topologies when the final input and output connection relations are made equal."

V. Applications

MCs are often used in AC variable speed drives for low and medium rang voltage applications. MCs widely used in aircrafts due to their light weight and compact in size Since MC has the capability to regenerate the energy feedback to the utility, which is used in cranes and elevators. Future application expected in the field that uses PWM inverters and rectifiers such as in flywheels. The RB-IGBT (Reverse Biased- IGBT) achieves higher breakdown voltages and larger current capacity than conventional IGBT.

VI. Discussion On Simulation Results

In the previous chapter, we have seen the simulation of the Cycloconverter using Matrix Converter using the MATLAB/Simulink software. In this chapter, we see the simulation results for the Cycloconverter operation.
The proposed matrix converter for the step-up and step-down operation of Cycloconverter is implemented by simulation and simulation results are obtained using Simpowersystem block set in MATLAB/Simulink. The simulation model could be used to study the behavior of the SPMC as a Cycloconverter under a variety of the operating conditions, including different reference frequency with R and R-L load. The parameters used in simulating the model are shown in appendix.
Figure 6.1 (a) and Figure6.1 (b) shows the O/P voltage wave forms of step-down frequency of 12½Hz of modulation index of 0.7 and 1.0 for the input voltage of 50V and having a load of 50Ω. The simulation time is 0.08 sec. Here the input frequency is 50Hz. By increasing the modulation index, the output voltage can be controlled.
Figure 6.2 (a) and Figure6.2 (b) shows the O/P voltage wave forms of step-down frequency of 25Hz of modulation index of 0.7 and 1.0 for the input voltage of 50V and having a load of 50Ω. The simulation time is 0.08 sec. Here the input frequency is 50Hz. By increasing the modulation index, the output voltage can be controlled.
Figure 6.3 (a) and Figure6.3 (b) shows the O/P voltage wave forms of frequency 50Hz of modulation index of 0.7 and 1.0 for the input voltage of 50V and having a load of 50Ω. The simulation time is 0.08 sec. Here the input frequency is 50Hz.
Figure 6.4 (a) and Figure6.4 (b) shows the O/P voltage wave forms of step-up frequency of 100Hz of modulation index of 0.7 and 1.0 for the input voltage of 50V and having a load of 50Ω. The simulation time is 0.08 sec. Here the input frequency is 50Hz. By increasing the modulation index, the output voltage can be controlled.
Figure 6.5 (a) and Figure6.5 (b) shows the O/P voltage wave forms of step-up frequency of 150Hz of modulation index of 0.7 and 1.0 for the input voltage of 50V and having a load of 50Ω. The simulation time is 0.08 sec. Here the input frequency is 50Hz. By increasing the modulation index, the output voltage can be controlled.
Figure 6.6 (a) and Figure6.6 (b) shows the O/P voltage and O/P current waveforms of step down Cycloconverter of frequency 12½Hz of modulation index of 0.7 for the input voltage of 50V and having a load of 50Ω and 4mH. The simulation time is 0.08 sec. Here the input frequency is 50Hz.
Figure 6.7 (a) and Figure6.7 (b) shows the O/P voltage and O/P current waveforms of step down Cycloconverter of frequency 50Hz of modulation index of 0.7 for the input voltage of 50V and having a load of 50Ω and 4mH. The simulation time is 0.08 sec. Here the input frequency is 50Hz.
Figure 6.8 (a) and Figure6.8 (b) shows the O/P voltage and O/P current waveforms of Cycloconverter of frequency 50Hz of modulation index of 0.7 for the input voltage of 50V and having a load of 50Ω and 4mH. The simulation time is 0.08 sec. Here the input frequency is 50Hz.
Figure 6.9 (a) and Figure6.9 (b) shows the O/P voltage and O/P current waveforms of step-up Cycloconverter of frequency 100Hz of modulation index of 0.7 for the input voltage of 50V and having a load of 50Ω and 4mH. The simulation time is 0.08 sec. Here the input frequency is 50Hz.

Figure 6.10 (a) and Figure 6.10 (b) shows the O/P voltage and O/P current waveforms of step-up Cycloconverter of frequency 150Hz of modulation index of 0.7 for the input voltage of 50V and having a load of 50Ω and 4mH. The simulation time is 0.08 sec. Here the input frequency is 50Hz.
Matrix converter based Cycloconverter under different loads and different frequencies are simulated. From the results, matrix converter based Cycloconverter fulfill all the features of the ideal power frequency changer and overcome the disadvantages of conventional Cycloconverter.

A. Simulation Results Of R Load

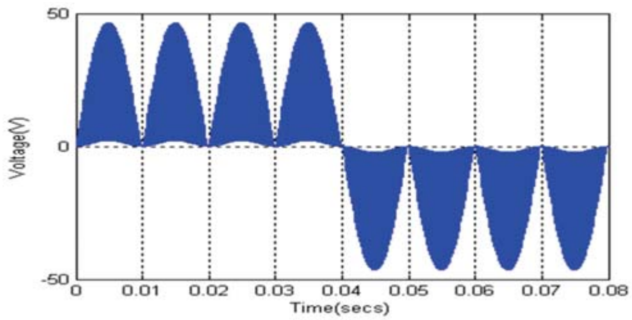

Figure 6.1(a): O/P voltage wave form of 12½Hz of modulation index of 0.7

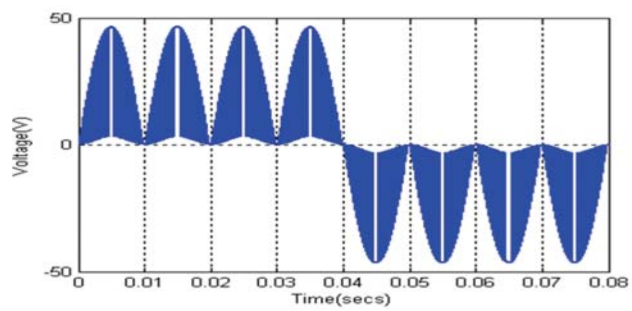

Figure 6.1(b): O/P voltage wave form of 12½Hz of modulation index of 1.0

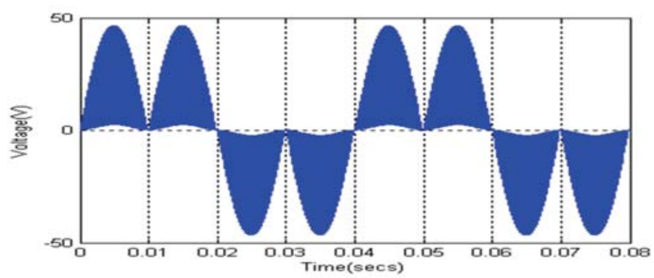

Figure 6.2(a): O/P voltage wave form of 25Hz of modulation index of 0.7

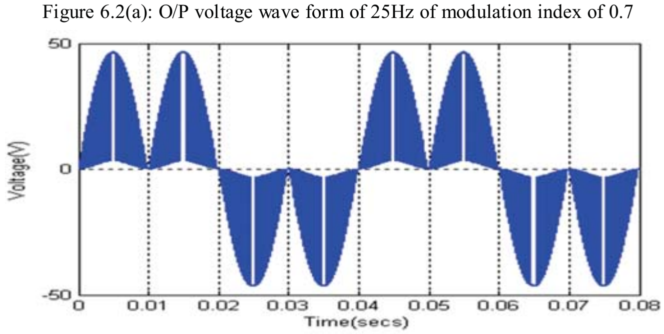

Figure 6.2(b): O/P voltage wave form of 25Hz of modulation index of 1.0

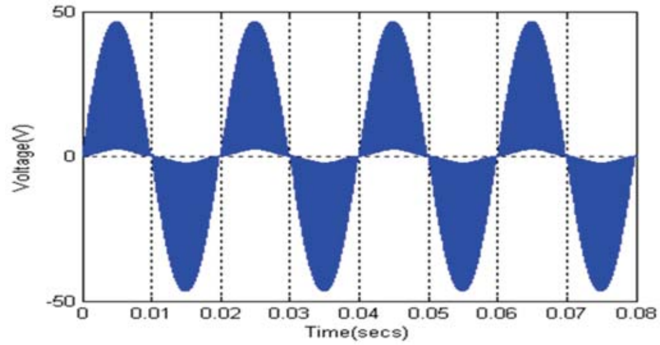

Figure 6.3(a): O/P voltage wave form of 50HZ of Modulation Index 0.7

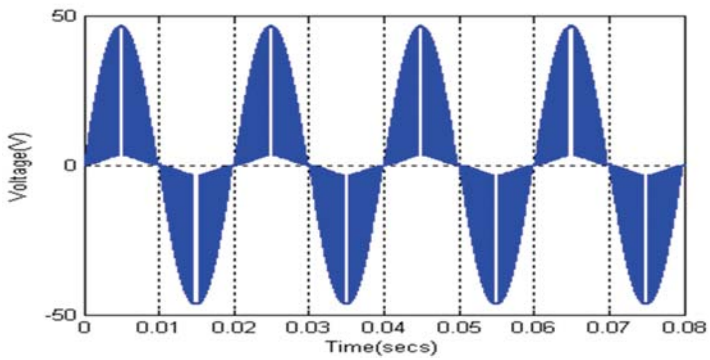

Figure 6.3(b): O/P voltage wave form of 50HZ of Modulation Index 1.0

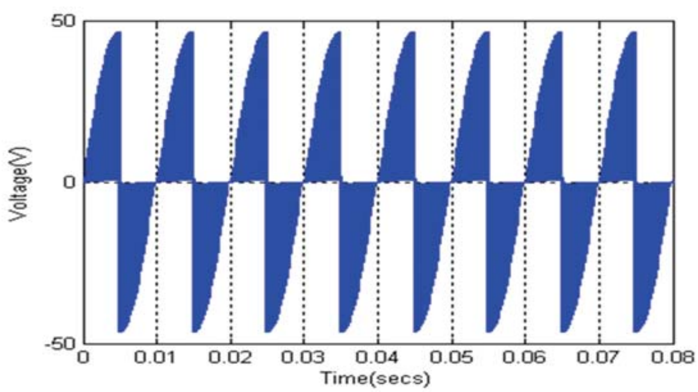

Figure 6.4(a): O/P Voltage wave form of 100 HZ of modulation index 0.7

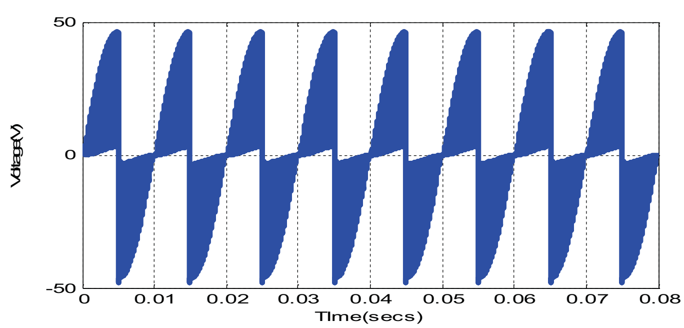

Figure 6.4(b): O/P Voltage wave form of 100 HZ of modulation index 1

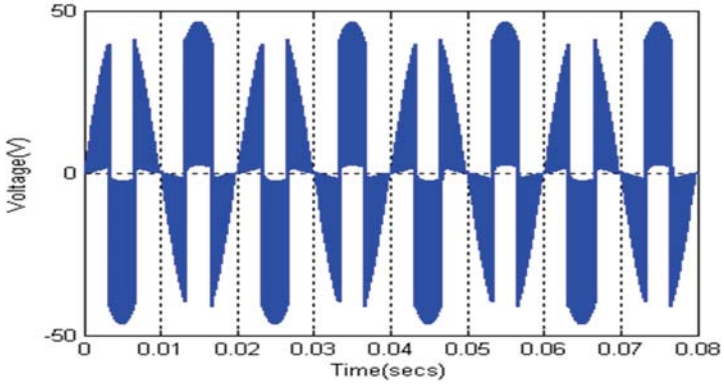

Figure 6.5(a): O/P Voltage waveform of 150 Hz of modulation index 0.7

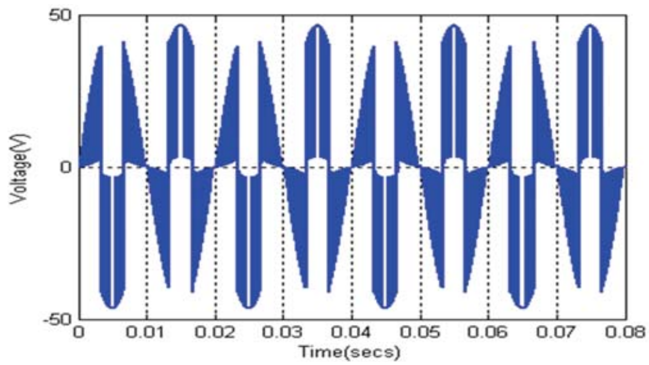

Figure 6.5(b): O/P Voltage waveform of 150 Hz of modulation index 1.0

B. Simulation Results Of R-L Load

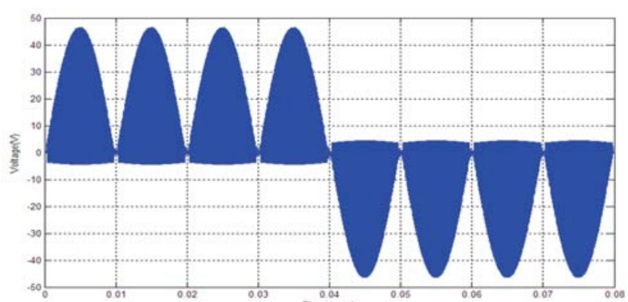

Figure 6.6(a): O/P Voltage waveform of 12½ Hz of modulation index 0.7

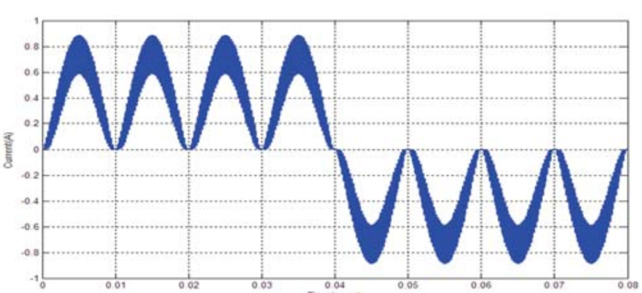

Figure 6.6(b): O/P Current waveform of 12½ Hz of modulation index 0.7

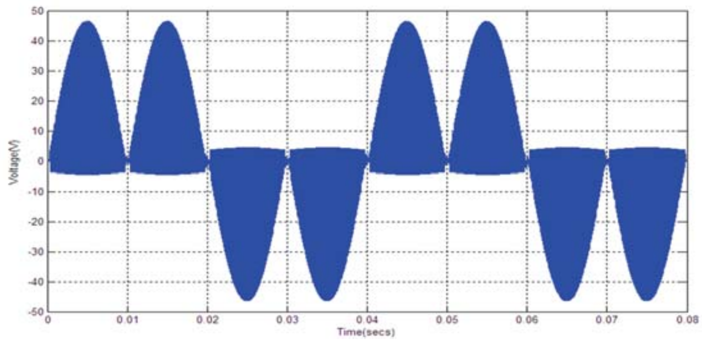

Figure 6.7(a): O/P Voltage waveform of 25 Hz of modulation index 0.7

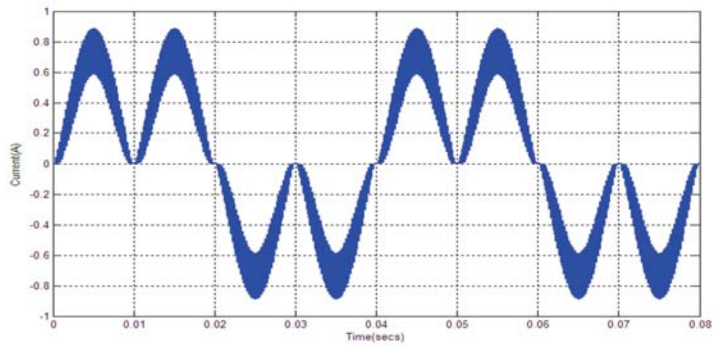

Figure 6.7(b): O/P Current waveform of 25 Hz of modulation index 0.7

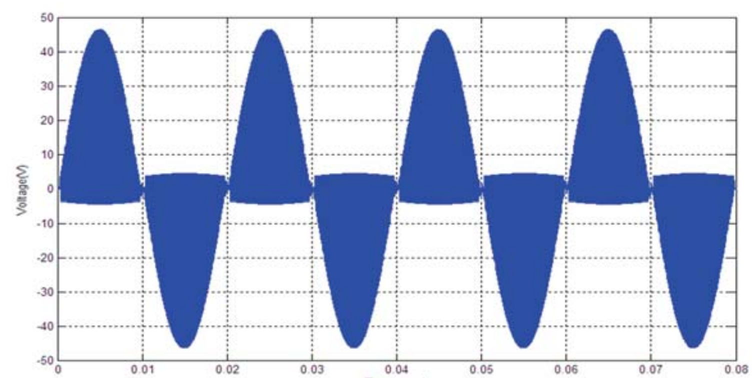

Figure 6.8(a): O/P Voltage waveform of 50 Hz of modulation index 0.7

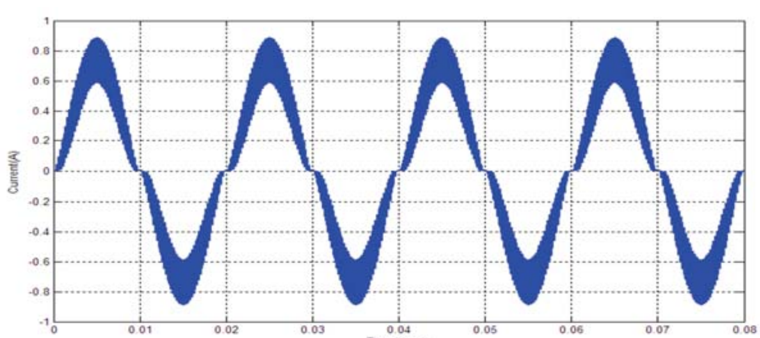

Figure 6.8(b): O/P Current waveform of 50 Hz of modulation index 0.7

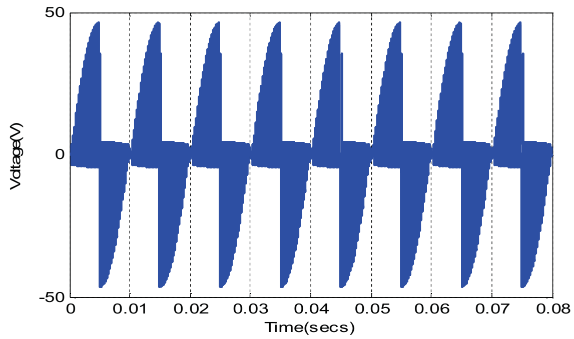

Figure 6.9(a): O/P Voltage waveform of 100 Hz of modulation index 0.7

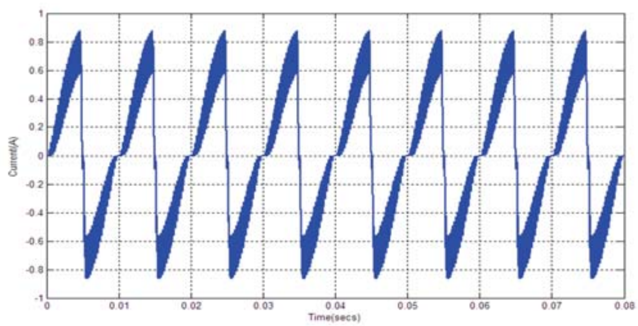

Figure 6.9(b): O/P Current waveform of 100 Hz of modulation index 0.7

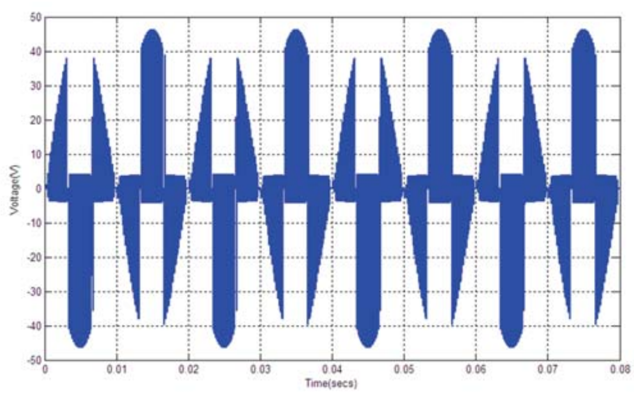

Figure 6.10(a): O/P Voltage waveform of 150 Hz of modulation index 0.7

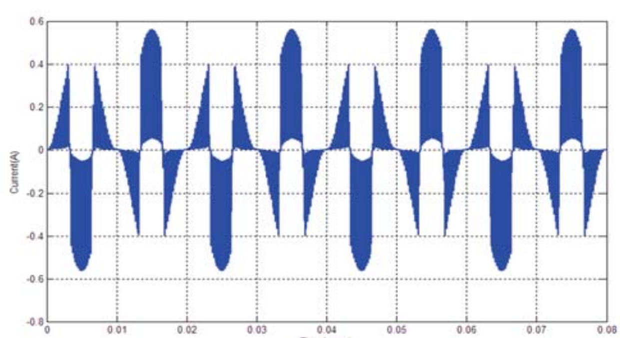

Figure 6.10(b): O/P Current waveform of 150 Hz of modulation index 0.7

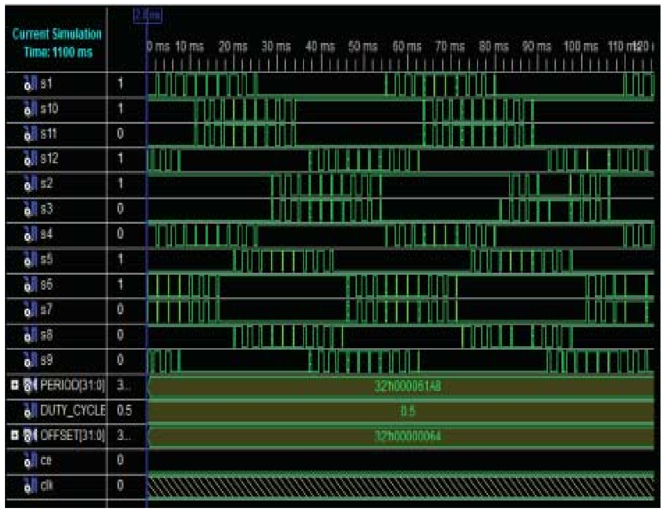

Figure 6.11: FPGA Gate Pulses to Matrix Converter

VII. Conclusion

In this project, the computer simulation model on SPMC for Cycloconverter operation using MATLAB/Simulink (MLS) software package has been presented.

- It includes the implementation of SPWM to synthesize the AC output supply for a given AC input. Matrix converter has many advantages like simple and compact circuit.
- Operation at unity power factor.
- Regeneration capabilities.
- Simulation results of SPMC illustrates that it is feasible to realize the converter in the various basic AC-AC converters that includes; AC controller, Step-up and Step-down frequency changer.
- A safe commutation technique is implemented to avoid current spikes by allowing the dead time.
- Matrix converter technology has potential benefits especially for applications where size, weight, and long term reliability are the important factors.
- Having these advantages, MC has very limited applications due to non-availability of full controlled bi-directional switch, complex control system.

In the near future, MC places a vital role by developing suitable control strategies.

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